

## High-Order Multi-Resolution Multi-Dynamics Modeling for FLEAT

Dr. Pierre F.J. Lermusiaux  
Department of Mechanical Engineering  
Center for Ocean Science and Engineering  
Massachusetts Institute of Technology; 5-207B  
77 Mass. Avenue  
Cambridge, MA 02139-4307  
phone: (617) 324-5172 fax: (617) 324-3451 email: [pierrel@mit.edu](mailto:pierrel@mit.edu)

Grant Number: N00014-15-1-2626

04/08/2015 - 09/30/2019

<http://mseas.mit.edu/Research/FLEAT/index.html>

### LONG-TERM GOALS

Our long-term goal is to *explain and quantify multiscale interactions at abrupt topography among flow systems, vortices, internal tides and slope currents, by using and developing high-order multi-dynamics HDG schemes for accurate process studies and by using and improving downscaling and two-way nesting schemes for realistic simulations and dynamics analyses.*

### OBJECTIVES

Our specific objectives for the present four-year project in the FLEAT region are to:

- Complete quantitative focused process-modeling studies of flows interacting with abrupt topography, with an emphasis on multiscale interactions among current systems, circulation features, eddies, topographic waves, internal tides and bottom gravity currents
- Further develop and utilize our high-order HDG schemes for such accurate scientific simulation studies of interactive dynamics (e.g. non-hydrostatic and hydrostatic) occurring around abrupt topography
- Refine and utilize our conservative implicit two-way nesting schemes, nested and open boundary conditions, downscaling schemes, semi-analytical estimation of circulation features and schemes for dynamically-adaptive generalized vertical coordinates, so as to allow efficient multi-resolution modeling
- Complete real-time forecasting and data-assimilative simulations during the FLEAT at-sea observation campaigns, perform multi-resolution re-analyses, and carry out realistic process studies and dynamics analyses
- Collaborate with the DRI team and transfer approaches, algorithms and simulations to DRI colleagues and NRL. Utilize and leverage the MIT Naval Officer education program.

## APPROACH

*Quantitative process studies with high-order multi-resolution multi-dynamics modeling.* In collaboration with the DRI team, we plan to explain and quantify multiscale interactions at abrupt topography. We will define and set-up flow configurations that encounter abrupt topographic gradients, with or without subsurface features and islands. This will involve time and 2D and 3D-in-space studies. To complete these studies, we will further develop our HDG codes towards a high fidelity modeling system, capable of multi-dynamics simulations at high-order over multi-resolution meshes. We plan to simulate and study nonlinear dynamics with non-hydrostatic or hydrostatic dynamics turned on. We plan to emphasize the multiscale interactions among the regional features observed, including non-hydrostatic stirring and mixing. We intend to utilize modeling and measurement results to inspire the development of process-oriented dynamical models for these interactions. We also plan to utilize our modeling results during the field campaigns to guide the sea sampling towards key processes and interactions.

*Downscaling and implicit two-way nesting of multiple dynamics in complex geometries.* For realistic simulations and dynamics analyses in complex geometries, we will refine and utilize our nested-grid boundary conditions and conservative multi-grid exchanges such that upscale and downscale effects of multiple dynamics are transferred accurately across the multi-resolution domains. We also plan to utilize and further evaluate our semi-analytical optimization scheme for the estimation of circulation features in complex multiply-connected regions, generalizing the “Island Rule”. We will improve our generalized vertical coordinate systems for primitive-equations (PEs) with a nonlinear free-surface, implementing model levels that optimally adapt to dynamics, for both our structured finite-volume and unstructured HDG codes. Finally, we plan to implement our HDG solver capability of separating non-hydrostatic and hydrostatic elements.

*Realistic data-assimilative multi-resolution modeling and dynamics analyses.* We will set-up and apply our MSEAS PE code for multi-resolution modeling of multiscale tidal-to-mesoscale processes in the FLEAT regions. This involves two-way implicit nesting, parameter tuning, data assimilation, and data-model comparisons. We intend to explain and quantify processes involved when regional currents encounter the abrupt topography, subsurface features and island chains, with an emphasis on multiscale interactions. We plan to complete re-analyses with telescoping two-way nesting, to be used for dynamics analyses. For dynamics analyses, we plan to utilize term-by-term and flux balances, LCSs analyses, time and space variability decompositions, and/or new internal tide extraction equations that we developed.

## WORK COMPLETED

This project just started. We have begun a literature review of the western Pacific and of the impact of abrupt topography. We have started studying and gathering data (both present and historic) for the western Pacific and islands, including bathymetry, in situ and remote observations, atmospheric fluxes and tidal fields. We have also downloaded 1/12 degree HYCOM fields from FSU and are working on obtaining access to the 1/25 degree resolution fields from NRL. We have completed a set of draft high-resolution model domains of the FLEAT region for use in our multiscale modeling systems. The largest of these domains was chosen to resolve the flows past the islands and topography, including internal tide/waves from the Strait of Luzon, while locating the boundaries of the domain to avoid intersecting the steepest bathymetry. In order to design these two-way nested multi-resolution domains, we created new schemes for the automated creation and quality control of land masks for complex

regions. These included algorithms for the automatic detection and correction of invalid land mask configurations.

## **RESULTS**

We found the HYCOM fields to be a useful adjunct when designing our modeling domains. In particular, the northern extent of our largest domain was chosen, in part, to avoid bisecting eddies and meanders from the Kuroshio, while the southern extent was chosen to model a retroflexion of the Southern Equatorial Current off the coast of New Guinea. The efficiency of creating new domains has been greatly improved by the new schemes and algorithms for the automatic creation and quality control of land masks. These schemes make it practical to create even more complex 2-way nested telescoping domains than were previously possible.

## **IMPACT/APPLICATIONS**

Impacts include a better understanding of flows in regions with abrupt topography and improved high fidelity data-assimilative multi-resolution modeling. Applications include advanced multi-resolution modeling for ocean science, ocean forecasting, naval operations, undersea surveillance and homeland security. Our developments of high-order multi-resolution multi-dynamics modeling schemes, of multi-dynamics downscaling schemes, and of conservative implicit two-way nesting in complex geometries are critical to modernize today's and enhance future naval operations. Our collaborative research will improve the understanding of how topographic interactions influence the structure of major current systems, generate internal waves and affect internal wave climates, and lead to vigorous unstable bottom gravity currents. Our results aim to improve ocean forecasting and impact acoustic performance forecasting in steep topography regions.

## **TRANSITIONS AND COLLABORATIONS**

We plan to collaborate with the other scientists involved in the DRI and provide them with our results.

## **RELATED PROJECTS**

Our NOPP project on "Seamless Multiscale Forecasting: Hybridizable Unstructured-mesh Modeling and Conservative Two-way Nesting" (N00014-15-1-2597) will benefit from, and contribute to, the present study.